THE ORIGIN OF RED BEDS

A STUDY OF THE CONDITIONS OF ORIGIN OF THE PERMO-CARBONIFEROUS AND TRIASSIC RED BEDS OF THE WESTERN UNITED STATES

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PART II

CONDITIONS OF DEPOSITION OF RED CLASTIC SEDIMENTS: MODERN TYPES

Seven distinct types of partly or wholly clastic modern red sediments have come to the attention of the writer, some of which, however, are closely related. The occurrence of each one of these types and its application to the Red Beds of the western United States is discussed in the following paragraphs.

Red clay of the deep-sea bottom.—This material is invariably very fine-grained, it contains little or no terrigenous matter of any kind, and it accumulates very slowly indeed, so that a thickness of it comparable to the total thickness of shales in any series of the western Red Beds is practically inconceivable. Nearly every part of all the series included in the Red Beds group exhibits incontestable evidence of shallow-water deposition, while the oceanic red clays are exclusively abysmal deposits. Such arguments could be multiplied almost indefinitely; it is quite clear that deep-sea red clay is not related to our problem in any way whatsoever.

Stream deposits derived from pre-existing Red Beds.—This type of deposits is illustrated by the flood-plain deposits of the Red River of the South, in Texas, Oklahoma, and Louisiana. This type cannot be dismissed so easily, for there are yet in existence masses of pre-Cambrian red sediments within the possible drainage areas tributary to some of the areas of the Red Beds. One objection to this source for the ferruginous matter of the Red Beds is that there were other sources for the sediments in question, nearer than

the pre-Cambrian series, and that much of the material of the Red Beds is known to have been derived from other rocks.

Arkosic stream deposits.—These are illustrated by deposits of limited extent in and downstream from the region occupied by the Sherman granite of Wyoming, which weathers to a coarse pink gravel, owing its color to a high content of undecomposed pink orthoclase. It is obvious that much the greater part of the color of the Red Beds is not due to pink feldspar; but in some of the very arkosic sediments of the Cutler and Dolores formations, and probably elsewhere, this is an element not to be ignored.[1]

Stream deposits deriving their coloring matter from ferruginous residual soils.—The fourth type of modern red sediments is exemplified by the continental portion of the deposits of the lower Amazon, and by smaller deposits in some of the rivers of the United States. Russell says:

> Each grain [of sand in residual soils left by the decomposition of crystalline rocks in the southern Appalachian Piedmont] is coated with a thin shell having a brownish or red color. Prolonged washing fails to remove this superficial coating, a fact which is well illustrated by the color of the sands deposited by the streams of Virginia and the Carolinas in the regions underlaid by crystalline rocks.[2]

Russell appears to assume that all of the ferric oxide produced by the decay of the crystalline rocks of this area is attached to grains of other minerals in this way. That which fills interstices between grains of sand in the final deposit,[3] as distinct from that which occurs in coatings on the grains, probably persisted independently, however, and was transported as a fine sediment like clay.[3]

The relation between surface weathering of the Piedmont crystalline rocks and the color of the Newark clastics in the neighboring areas, as developed by Russell, is very much the same as a relation recently advocated by Beede[4] between weathering of lime-

[1] Cf. Whitman Cross, Telluride Folio (No. 57), *Geol. Atlas of the U.S.*, *U.S. Geol. Survey*, 1899, p. 2.

[2] I. C. Russell, "Subaerial Decay of Rocks," *U.S. Geol. Survey Bull. No. 52*, 1889, p. 14.

[3] See p. 164, this volume.

[4] J. W. Beede, "Origin of the Sediments and Coloring Matter of the Eastern Oklahoma Red Beds," abstract in *Bull. Geol. Soc. America*, XXIII (1912), 723–24.

stones and the color of the Red Beds of eastern Oklahoma. He says:

> The coloring matter is thought to have been derived from the solution of the 7,000 or 10,000 feet of pre-Carboniferous limestone which formerly covered the Arbuckle-Wichita Mountains and much of the surrounding region. The solution of the limestone furnished optimum conditions for the oxidation of its iron content, as it does at the present time in the limestone regions of the Mississippi Valley, southern Europe, West Indies, and elsewhere. Moreover, the solution of the pre-Carboniferous limestones and the conglomerates of the Arbuckle-Wichita region now in progress produces a red residuum practically indistinguishable from Red Beds sediments. The red granites, red porphyries, and other crystalline rocks of the region under discussion contributed their shares of material to the Red Beds.[1]

The Red Beds of the Grand Canyon section are underlain by the famous Redwall limestone, and limestones underlie the Red Beds practically throughout the Plateau province and in the San Juan region. Areas in Colorado of history similar to that of the Arbuckle-Wichita region, in that highlands existed there after the earlier Paleozoic limestones were deposited, and during Red Beds times, may well have played the same part in the central Rocky Mountain region that Beede assigns to the Arbuckle-Wichita uplift in Oklahoma. The existence of such highlands is demonstrated by the great conglomerates in the Colorado Red Beds.[2] Various other land-masses which contributed material to the sediments of the Red Beds[3] may have been quite as efficient as the Arbuckle-Wichita highlands in producing residual soils stained by ferric oxide.

It is evident from the foregoing discussion that stream deposits deriving their coloring matter from ferruginous residual soils are probably of no little importance in the Red Beds, and may constitute a major part of the series of sediments included under that term.

Terrigenous marine clastics.—The fifth type of modern red sediments is illustrated by deposits in the Atlantic Ocean off the mouth of the Amazon River.[4] This is an exceptional occurrence,

[1] Beede, *op. cit.*

[2] See pp. 244-245. [3] See pp. 245-246.

[4] John Murray, *Challenger Reports, Deep Sea Deposits*, 1891, p. 234.

as most terrigenous red muds lose their color on entering the sea. A vivid description of this process of loss of color in the case of certain rivers in Nova Scotia is given by Dawson, as follows:

> This harbour [Pictou] receives the waters of three rivers and several smaller streams, which in times of flood carry into it large quantities of reddish mud, which sometimes discolours the whole surface. This mud, with similar sediment from the shore of the harbour, is deposited in the bottom, and there undergoes a remarkable change of colour. A portion of old mud recently taken from the bottom is of a dark grey colour, and emits a strong smell of sulphuretted hydrogen. . . . . The iron of the red clay has entered into combination with sulphur, and this is probably obtained from the sulphates contained in the sea-water, by the deoxidizing influence of decaying vegetable matter . . . . which grows abundantly on the mud flats. . . . . In some parts of the deposit forming in Pictou harbour, the vegetable matter which caused the change of colour is so completely decomposed that no visible fragments of it remain.[1]

The chemical action of marine organic matter is summarized by Clarke in part as follows: "Decomposing organic matter reduces the sulphates of sea-water to sulphides, which by reaction with carbonic acid yield sulphuretted hydrogen. Bacteria also assist in the process."[2]

The interbedding of marine limestones with Red Beds shales in the Texan section is consistent with an origin for the shales similar to that of the semi-oceanic sediments from the Amazon River. The interbedding of gray and green strata with red ones in certain of the Red Beds series indicates an oscillation of dominance between oxidizing and deoxidizing conditions, such as might be caused at the margin of the sea or in the waters of an inclosed basin by variations in the rate of sedimentation or in the abundance of organic matter. The marine type of deposition of red sediments is not to be neglected, therefore, in an attempt at reconstruction of the conditions of origin of the Red Beds; though the complete absence of marine fossils from other parts of this group of sediments, together with independent proof of the continental origin of most of the group, shows that the marine type cannot be of more than subordinate importance.

[1] J. W. Dawson, "On the Colouring Matter of Red Sandstones and of Greyish and White Beds Associated with Them," *Quar. Jour. Geol. Soc. London*, V (1848), 29.

[2] F. W. Clarke, "The Data of Geochemistry," 2d ed., *U. S. Geol. Survey Bull. No. 491*, 1911, pp. 136-137.

Deposits of desert lakes or playas.—For an example of the sixth type of present-day red sediments, deposited under water in desert lakes or playas, we turn to Chinese Turkestan. The following description, by Huntington, relates to the northern extremity of the bed of Lop Nor, near the southern base of the Kuruk-Tagh or Dry Mountains: "Beyond the fatiguing plain of salt [dry bed of the dwindled lake Lop Nor] we found easy traveling for a time. A fantastic red plain, the soft, dry bed of an older expansion of the lake, glittered with innumerable gypsum crystals."[1]

Here we have a recent deposit of gypsum (or, more properly, selenite), in which the crystals presumably are imbedded in a red clay or mud. The relations here described could be duplicated by many minor deposits of gypsum in the Red Beds of the western United States. Farther out toward the center of the lake floor occur the purer non-clastic sediments, which in the case of Lop Nor are described as salt beds. The coloring matter of the clays probably was derived, as in the two preceding types of modern red sediments, from the decay of rocks on the neighboring uplands.

Red dune sands.—The seventh and last type differs from all the others in being an eolian deposit. Red dune sands are exceptional rather than the rule in the desert regions of today, but they occur in sufficient abundance to warrant attention. Their most striking occurrence is in the Nefood or Red Desert of Northwestern Arabia. The following quotation is from Palgrave's narrative of a journey taken in 1862: "We were now traversing an immense ocean of loose reddish sand, unlimited to the eye, and heaped up in enormous ridges, ... undulation after undulation, each swell two or three hundred feet in average height."[2]

The extreme breadth of the Nefood is about 150 miles, its greatest length about 400 miles.[3]

Huntington mentions "an almost absolutely barren area of reddish or yellowish sand dunes, from ten to a hundred or more feet

[1] Ellsworth Huntington, *The Pulse of Asia* (Boston and New York: Houghton Mifflin Co.), p. 254.

[2] W. G. Palgrave, *Central and Eastern Arabia* (London: Macmillan, 1908), pp. 62–63.

[3] See J. A. Phillips, "The Red Sands of the Arabian Desert," *Quar. Jour. Geol. Soc. London*, XXXVIII (1881), 110–13.

high"[1] between Karakir and Keriya River, in the southern border of the Takla Makan Desert, Chinese Turkestan. Some 40 or 50 miles farther north is the district described in the following passage: ". . . . ridge after ridge of sand, fifty to one hundred feet high. . . . . Their gently sloping backs to windward were gray with a cover of rather coarse sand, while their steep fronts to leeward were pale brick-red with the fine sand of the main desert."[2]

There are in the Red Beds of the western states no sandstones of this type of such great thickness as that of the Nefood sands, yet the possibility must be recognized that there may be local sandstone members of this origin in the series. A region dry enough to admit of the production of great bodies of gypsum might easily be transgressed by shifting sands; or the two types of deposition might exist side by side, as they do today in the region of Lop Nor and Takla Makan. The coarsely cross-bedded sandstones of the Chugwater formation along the eastern base of the Wind River Range in Wyoming, for instance, will bear further investigation with this possibility in mind.

EVIDENCE OF FEATURES OTHER THAN COLOR AS TO THE CONDITIONS UNDER WHICH THE RED BEDS WERE DEPOSITED

The wide range in grain shown by the Red Beds of various parts of the West, and the varying quantity of non-clastic sediments in the group, show that a variety of conditions existed in this region during the time the Red Beds were accumulating, as is to be expected from the great extent of the group. What the varying relations were will be pointed out as accurately as possible in the following pages.

Evidence of conglomerates as to the sites of land-masses.—Conglomerates, by the pebbles which they contain, display more clearly than other sediments the source of their component materials. We can therefore determine with some confidence the sites of the land-masses which gave rise to the Red Beds, where these are conglomeratic. In southeastern Oklahoma, Beede[3] has presented facts to show that the lower Red Beds sediments were derived from

[1] Huntington, *op. cit.*, pp. 183–84.

[2] *Ibid.*, pp. 184–85.

[3] *Op. cit.*

the Arbuckle-Wichita region. Near the border of the present Arbuckle and Wichita mountains, limestone conglomerate and conglomerate of crystalline rocks dovetail into Red Beds sediments of finer grain. The limestone undoubtedly was derived from earlier Paleozoic formations, and the crystalline fragments from more ancient rocks, both of which are known to have been exposed in the uplifted region just named. Increasing thickness of sediments toward the mountains testifies to the same relation. To what distance sediments from this isolated highland may have been distributed is largely a matter of conjecture. The entire Red Beds series thins northward from this area to the northern limit of their outcrops in Nebraska, and in the same direction clastic sediments give place in part to limestones: both of which facts signify increasing distance from the source of terrigenous material. The small outlier of Red Beds in central Iowa, which probably is to be correlated with the Cimarron series of Kansas,[1] is composed chiefly of red shale and gypsum, likewise indicating relatively clear-water conditions. It would be an unwarranted assumption, however, to assume that the Kansas and Iowa Red Beds were derived wholly from the Arbuckle highlands. The greater areas of upland which probably existed in the region surrounding and including the pre-Cambrian areas of Minnesota and Wisconsin may have been important sources of material, as may also the ancient Appalachian continent of the East; but it may safely be said that their influence is not exhibited in the strata now available for study, as the influence of the Arbuckle highland so clearly is.

Similar criteria may be applied to the great conglomerates of the Fountain and Wyoming formations of the Front Range, and to those of central and southwestern Colorado. The conglomerates of the Front Range Red Beds and of the Maroon formation of the Anthracite, Crested Butte, and Tenmile districts are made up chiefly of fragments from pre-Cambrian crystallines,[2] which still

[1] Cf. F. A. Wilder, "The Age and Origin of the Gypsum of Central Iowa," *Jour. Geol.*, XI (1903), 723–48.

[2] See Whitman Cross, Pikes Peak Folio (No. 7), *Geol. Atlas of the U.S., U.S. Geol. Survey*, 1894; G. K. Gilbert, Pueblo Folio (No. 36), 1897; and G. H. Eldridge, "Description of the Sedimentary Formations," Anthracite-Crested Butte Folio (No. 9), 1894.

outcrop in wide areas in various parts of the ranges. The Maroon conglomerates include also fragments of quartzite and limestone from older sediments. The composition of these formations renders it certain that their materials were not carried far from their sources; it is therefore certain that there were highlands, and there may have been mountain ranges of no insignificant relief in various parts of Colorado during Red Beds time—which here probably was included for the most part within the Pennsylvanian and Permian periods.

The coarser beds of the Cutler and Dolores formations in southwestern Colorado show by their composition that they also were derived very largely from igneous and metamorphic terranes.[1] The studies of Cross[2] have shown that the northern part of the San Juan region itself, as well as the neighboring Uncompahgre Plateau, was exposed to erosion between early Cutler and Dolores time—at or near the beginning of the Mesozoic era. This upland may have furnished sediment to a considerable part of the plateau province to the west and southwest. Cross is of the opinion that the absence of the Red Beds on the Uncompahgre Plateau is due to post-Dolores erosion;[3] but the conglomeratic character of the Red Beds in the San Juan Mountains demands that a source for those sediments be found close at hand. In the absence of any conclusive evidence that the Red Beds ever were deposited over the plateau in question, it may be regarded at least provisionally as the probable site of that source.

The sediments of the Plateau province, on the whole, do not indicate mountainous topography in the vicinity; but their great thickness (maximum more than 5,000 feet, excluding non-clastic beds) calls for the existence of a land area contributing sediments to this region for a long period of time. Such an area may well have existed toward the south and southwest, in Mexico, southwestern

[1] See Whitman Cross and others, in the following folios of the *Geol. Atlas of the U.S., U.S. Geol. Survey:* Telluride (No. 57), 1899; LaPlata (No. 60), 1899; Silverton (No. 120), 1905; Needle Mountains (No. 131), 1905; Ouray (No. 153), 1907; Engineer Mountain (No. 171), 1910.

[2] Whitman Cross, "Stratigraphic Results of a Reconnaissance in Western Colorado and Eastern Utah," *Jour. Geol.*, XV (1907), 648–49, 654–56.

[3] *Ibid.*, pp. 648–49.

Arizona, and southeastern California, or farther north in the Great Basin, where no sediments contemporaneous with those in question are known to occur.[1] The absence of sediments between the Mississippian and the Cretaceous in the El Paso quadrangle[2] in western Texas may be due altogether to erosion following deformation at the close of the Jurassic period, but this gap in the record makes it possible that land may have existed even here during Red Beds times.

Richardson has concluded from his studies of the Black Hills Red Beds[3] that those sediments were derived chiefly from the Rocky Mountain area to the southwest and west. West of central Wyoming, the Red Beds group thickens, and the quantity of limestone and gypsum in it diminishes, continuously westward across the Idaho border, suggesting a source of sediments in that direction. The great thickness of the group all along the Wasatch Range, wherever it is exposed, extends this suggestion to include a considerable land area trending north and south from southern Idaho into central Utah.

Significance of non-clastic sediments.—The more important limestone members of the Red Beds record the existence of extensive bodies of clear and not excessively salty water during parts of the Pennsylvanian period in central Texas, in the Plateau Province, in the San Juan region, and in southeastern Wyoming; during the Permian, in the region north and east of Great Salt Lake (in the early part of the Permian, marine deposition throughout much of Wyoming, prior to the initiation of Red Beds sedimentation there), and in western Texas; and in the Triassic, in northeastern Arizona.

[1] Cf. paleogeographic maps by the following authors: T. C. Chamberlin and R. D. Salisbury, *Geology* (New York: Henry Holt & Co., 1909), II, 545; III, 3 and 62; W. B. Scott, *An Introduction to Geology* (New York: Macmillan, 1909), pp. 616, 662; Charles Schuchert, "Paleogeography of North America," *Bull. Geol. Soc. America*, XX (1909), Pls. 84–88 inclusive.

[2] G. B. Richardson, El Paso Folio (No. 166), *Geol. Atlas of the U.S. U.S. Geol. Survey*, 1909.

[3] G. B. Richardson, "The Upper Red Beds of the Black Hills," *Jour. Geol.*, XI (1903), 365–93.

The extraordinary development of gypsum in the Permian Red Beds deserves more than passing comment. In association with salt, deposits of gypsum are interpreted as indicating aridity of climate at the time of deposition, and of formation in at least partially inclosed basins by the evaporation of bodies of water not freely connected with the open sea.[1] This occurrence of gypsum, supported by independent evidences of continental origin for the Red Beds, has been the one strongest influence in establishing the idea that the red color itself is an indication of aridity. The absence of gypsum from many series of Red Beds, and its occurrence in series free from Red Beds, make it necessary to investigate the two problems on their own independent merits.

Rock salt is of relatively rare occurrence in the group of sediments under discussion. Since the saturation point of gypsum in aqueous solution is much lower than that for common salt, it is logical to suppose that the deposition of gypsum unaccompanied by rock salt signifies a condition of aridity and of continuous or intermittent supply of normal sea-water or of fresh water such as to maintain a degree of salinity more moderate, for example, than that of Great Salt Lake at present, but sufficient to cause the continued precipitation of gypsum. Such a condition might be kept up by a limited or intermittent connection between the open sea and the basin of deposition.

The relation of the gypsum and salt deposits of the West to the Red Beds proper suggests a relation similar to the relation between marine limestones and terrigenous sediments. The Rustler dolomite and the Castile gypsum of the Texan portion of the Pecos Valley give place northward to typical Red Beds with a few interbedded strata of dolomite and gypsum. May not the gypsum, as well as the dolomite, be but the complements of the red clastic sediments, deposited in the clear central waters of an inland sea, or in lagoons near or at sea-level but partly or wholly cut off from the sea; while clastic sedimentation went on nearer the shores and on river deltas or flood-plains yet nearer to the sources of sediment?

[1] Cf. Wilder, *op. cit.*

The clastics: minor structural features.—Returning to the clastic sediments, we may draw still further inferences regarding the conditions under which they were deposited, from their structural characteristics and mineral composition. Ripple-marks and mud-cracks in the majority of Red Beds sections testify to the prevailing shallowness of the water in which these sediments were laid down. Mud-cracks repeated in layer after layer, as in some parts of the Red Beds, mean complete emergence and at least partial drying, after the deposition of each stratum and before that of the next following. Shallow water means shifting currents, and these too are recorded clearly by cross-bedding in most sandstones of the series, and by rapid variation along the strike in the shaly members as well. We do not have, in the clastic portions of the Red Beds, and seldom do we find in the non-clastic members thereof, the continuity of a single type of sedimentation over wide areas and through long periods of time, which are to be expected in truly subaqueous or marine deposits. Furthermore, imperfect assortment, which is one of the universal characteristics of fluviatile deposits, is the rule in the Red Beds. The sandstones are earthy, the shales sandy, the conglomerates gritty, etc. Each of these characteristics is suggestive of subaerial conditions, and the occurrence of all of them together in the same series, and widely distributed through that series, is conclusive testimony to such an origin.

The clastics: mineral composition.—From the mineral composition of the clastic sediments we may infer something of the conditions of weathering and transportation which preceded their deposition. The high proportion of feldspar in many of the Red Beds shales and sandstones indicates a preponderance of mechanical disintegration over chemical decomposition. The abundance of undecomposed mica flakes in most Red Beds confirms this interpretation. Transportation may precede complete decomposition because of exceptional rapidity of disintegration, exceptional slowness of decomposition, or both. Rapid disintegration may be caused by such factors as high relief and great daily or seasonal range of temperature; slow decomposition by low rainfall or low temperatures. Low temperatures throughout the year explain

the slowness of chemical decomposition in polar regions; aridity explains it in the desert, where disintegration is accelerated by great daily range of temperature; and disintegration is accelerated on mountain peaks by all of the factors mentioned. Absence of vegetation, which itself is dependent chiefly on climatic factors, is unfavorable to rapid decomposition of rocks because of the important part played by organic acids in the chemical processes of weathering.

As we have seen, the occurrence of gypsum indicates aridity and high temperatures, so that we may rule out the hypothesis of Arctic conditions as applicable to the Red Beds. The coarse conglomerates in certain parts of the Red Beds are indications of high relief in certain areas and at certain times.

The occurrence of limestone conglomerate in the Red Beds of the Arbuckle-Wichita region emphasizes the predominance of disintegration over decomposition in that area, as limestone is one of the most readily decomposed of rocks. If the limestone conglomerates of the Cutler formation were detrital, it would have the same significance concerning the processes of the San Juan region; but it has been interpreted otherwise.

Evidence supplied by fossils.—It has been stated that marine limestones carrying abundant faunal remains occur in central Texas interbedded with the Permo-Carboniferous Red Beds. The significance of the relations found in this region is well summarized by Chamberlin and Salisbury, as follows:

The oldest part of the Permian system (*Wichita formation*) indicates that the critical attitude which characterized the surface farther east during the Pennsylvanian period now affected Texas, for the beds are partly of marine and partly of fresh-water origin. These beds are succeeded by a formation of limestone (the *Clear Fork*) of marine origin, which overlaps the Lower Permian. The Upper Permian (*Double Mountain* formation) which follows indicates a reversal of relations, for much of Texas was again cut off from the ocean, and converted into an inland sea, or into inland seas, in which the phases of deposition common to such bodies of water took place. Occasional beds of limestone with marine fossils point to occasional incursions of the sea, while deposits of salt and gypsum point with equal clearness to its absence, or to restricted conditions, and to aridity of climate.[1]

[1] T. C. Chamberlin and R. D. Salisbury, *College Geology* (New York: Henry Holt & Co., 1909), p. 661.

The large and varied vertebrate fauna which has now been described from the clastic members of the Red Beds series in various parts of the Southwest[1] includes no forms requiring other than a land or fresh-water habitat, with the exception of fish remains in some of the marine beds just mentioned. In general, then, it is true that the paleontological evidence corroborates the purely stratigraphic and lithologic evidence for a continental origin for at least the greater part of the Red Beds. In certain places and at certain horizons the fossil remains, both plant and animal, are sufficiently abundant and of such types as to eliminate the possibility of extreme aridity as a continuously prevalent condition. The bone beds and petrified forests of northeastern Arizona, for instance, prove that during the time of deposition of the Shinarump group,[2] at least, there was a water supply in that vicinity sufficient to permit the support of abundant land life, both vegetable and animal. It is possible, however, that this water supply was derived from precipitation in a distant region, like the waters of the Nile delta. In the underlying Permian, which contains more salt and gypsum than the other members of the series in this district, vertebrate remains are absent. The Permian of the neighboring Kanab Plateau has yielded an extensive invertebrate fauna[3] suggesting brackish-water environment.[4]

Summary.—The most salient of the facts and inferences brought out by the foregoing discussion of the significance of features other than color as to the conditions of deposition of the Red Beds may be summarized as follows: (1) rapid erosion on land-masses of considerable relief; (2) decomposition not complete in advance of transportation; (3) sediments diminishing in thickness and in coarseness of grain away from sources of material, and clastic

[1] See especially various publications by S. W. Williston in the *Journal of Geology*, 1903–13.

[2] L. F. Ward, "Geology of the Little Colorado Valley," *Am. Jour. Sci.*, 4th Ser., XII (1901), 401–13. On p. 405 is the following statement: "The Shinarump constitutes the horizon of silicified trunks and there is no part of it in which fossil wood does not occur in great abundance."

[3] See C. D. Walcott, "The Permian and Other Paleozoic Groups of the Kanab Valley, Arizona," *Am. Jour. Sci.*, 3d Ser., XX (1880), 221.

[4] Interpretation by Eliot Blackwelder (personal communication).

sediments giving place to non-clastic in the same direction; (4) fluviatile deposition most important; (5) all deposits in relatively shallow water, or subaerial; (6) oscillating marine and non-marine conditions at edge, non-marine in most of region of deposition; (7) moderate aridity long continued in some parts of the region of deposition, alternating with less arid conditions in other parts.

These conditions coincide to a remarkable degree with those inferred from the study of modern red sediments.

RELATION OF DIASTROPHISM TO RED BEDS SEDIMENTATION

It may well be asked at this juncture why it is that earlier Carboniferous clastics underlying the Red Beds of Oklahoma and other states are not similarly colored. The difference in color, since this has been shown to be a feature dating from the time of sedimentation,[1] must be due to differences of some sort in the geographic conditions of the times when the successive series were deposited. One of these differences is the emergence of the plains of deposition. Another may be found in the fact that some, at least, of the highlands from which the Red Beds derived their materials were not in existence in the earlier part of the Paleozoic era. The Arbuckle-Wichita uplift probably dates from the later part of the Pennsylvanian period; and there may have been mountain-building in Colorado at the same time, as the stratigraphic relationships of the scattered Paleozoic sediments in that state seem to indicate. Dr. Blackwelder[2] calls attention in this connection to the fact that the general trend of the Arbuckle-Wichita folding is directly in line with the suspected areas in Colorado. Local climatic changes influencing the type of sedimentation may have been brought about by these changes in topography. The general continental expansion of North America from Pennsylvanian to Jurassic times leads one to expect extreme types of continental climate, including aridity, the localization of which would depend largely on the configuration of the continent.

The deposition of red sediments derived from ferruginous soils means either the development of red soils and the transportation of the material thereof without hydration, or the development of

[1] See discussion of this point, pp. 162–67, this volume.

[2] Personal communication.

limonitic ferruginous soils and the dehydration thereof during transportation. The development of ferruginous soils is the chief prerequisite to the deposition of Red Beds of the western type.

The areas from which the Red Beds derived their materials certainly included uplands, and in part at least they are known to have been possessed of fairly rugged relief; they were therefore in all probability the sites of more abundant rain than fell upon the plains or delta flats upon which the Red Beds were in large part deposited. The combination of well-watered highlands with less humid or semi-arid lowlands furnishes the conditions for the development of red soils, and at the same time provides for the transportation and deposition of the sediments derived from them without extensive hydration or reduction of the ferric oxide constituent during the transfer.

An unusually extensive development of red soils during the time of deposition of the Red Beds might have been due, in some part at least, to the higher proportion of oxygen inferred by Chamberlin and Salisbury[1] to have existed in the atmosphere at this time.

SUMMARY

The several steps which have been followed in the interpretation of the color of the Red Beds, and the results obtained, may be summarized as follows:

1. The ferruginous matter which gives the Red Beds their color has been present in the series in very nearly its present distribution and arrangement since the time of sedimentation.

2. This material has suffered no extensive change of ferrous to ferric iron, or vice versa, since the time of sedimentation; the proportion and present distribution of these compounds in the series were influenced most largely by the original distribution of organic matter.

3. Changes in the degree of hydration of the ferric oxide in the Red Beds since sedimentation probably have not been of great importance; and hydration probably has been quite as active as the reverse process during this time.

[1] T. C. Chamberlin and R. D. Salisbury, *Geology* (New York: Henry Holt & Co., 1909), II, 665.

4. The ferruginous matter of the Red Beds was transported and deposited almost, if not quite, wholly as a mechanical sediment, both independently and as a coating upon grains of other material.

5. The types of sediments probably most important in the Red Beds group are stream deposits, submarine fluviatile deposits, and playa deposits, all predominantly of red color, and all deriving at least the greater part of their ferric oxide from ferruginous residual soils. Of these types the first is by all odds the most important.

6. The study of characteristics of the Red Beds other than color bears out the conclusion stated in No. 5.

7. The inauguration and cessation of Red Beds sedimentation probably were connected closely with climatic and topographic changes involved in the orogenic history of the continent.

The colors which distinguish Red Beds from other series are due to a combination of lithologic, topographic, and climatic factors in the regions of denudation and in those of deposition, which have not been reproduced over so great an area in more recent times.

It is apparent that, in accordance with Barrell's view,[1] "red color in sediments is not in itself an indication of aridity"; for the material of red ferruginous soils may be transported and deposited in regions of high rainfall, or even under the sea, without change of color; and red soils themselves develop in regions of heavy rainfall. But since the dehydration of the limonitic material of non-red ferruginous soils, as well as the continuance of the relatively anhydrous condition of the hematitic material of red soils, is favored by aridity in the regions of transportation and deposition, therefore red sediments should form a larger part of the sediments of arid than of humid regions.

[1] Joseph Barrell, "Upper Devonian Delta of the Appalachian Geosyncline," *Am. Jour. Sci.*, 4th Ser., XXXVI (1913), 437.